National Renewable Energy Laboratory
*Innovation for Our Energy Future*

# PHOTOCONDUCTIVE DECAY LIFETIME AND SUNS-$V_{OC}$ DIAGNOSTICS OF EFFICIENT HETEROJUNCTION SOLAR CELLS

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## Introduction

### Techniques for Optimization of Si heterojunction (SHJ) solar cells

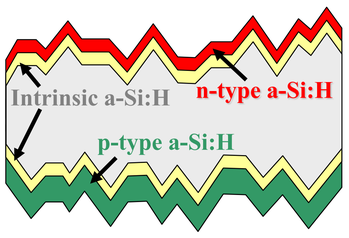
Sinton WCT-Boule

Sinton Lifetime Measurement
1. Photoconductive decay technique
   - Non-contact
2. Can measure lifetime after a-Si:H deposition
   - Amorphous silicon (a-Si:H) excellent surface passivation
   - Surface recombination velocity <15 cm/s
3. Reliable Transient Mode Lifetime and Implied $V_{oc}$

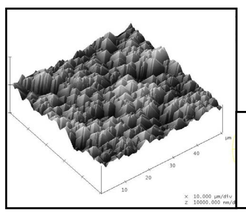
Sinton Suns-$V_{oc}$

Sinton Suns-$V_{oc}$ Measurement Apparatus
1. Rapid Flash Lamp Technique
2. Can be performed after ITO deposition
3. Reliable $V_{oc}$ data before contacts & finished cell
   - Troubleshoot shunting, series resistance finished cells

## 1: Heterojunction Deposition

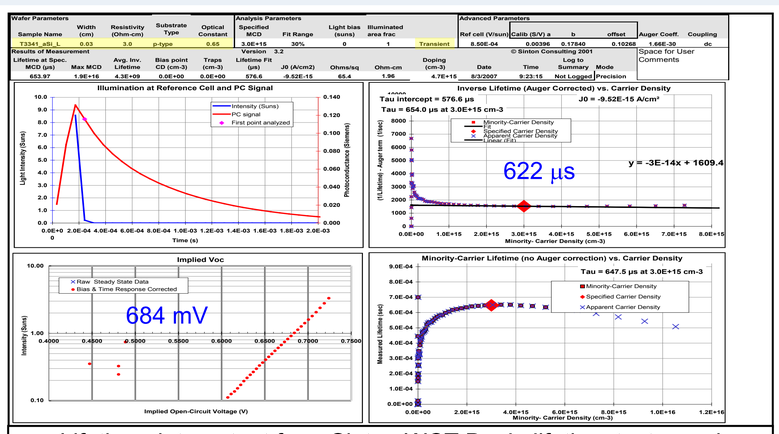



- Isotropic texturing and standard clean (RCA)
- Strip protective chemical oxide
  24:1 DI $H_2O$ and (49%)HF
- Deposit front emitter
  3 nm a-Si:H(i): 100°C
  4-5 nm a-Si:H(n): 200°C
- Deposit base contact
  3 nm a-Si:H(i): 100°C
  5-20 nm a-Si:H(p): 250°C



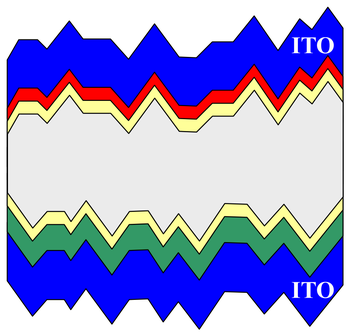
AFM measurement of as textured Silicon wafer

### Lifetime Measurement: a-Si:H/c-Si

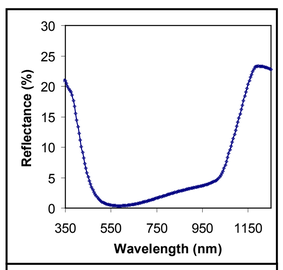



Lifetime data output from Sinton WCT-Boule lifetime tester and analysis after a-Si:H deposition n/i/FZ-Si(p)/i/p for 19.1% device

## 2: ITO Deposition

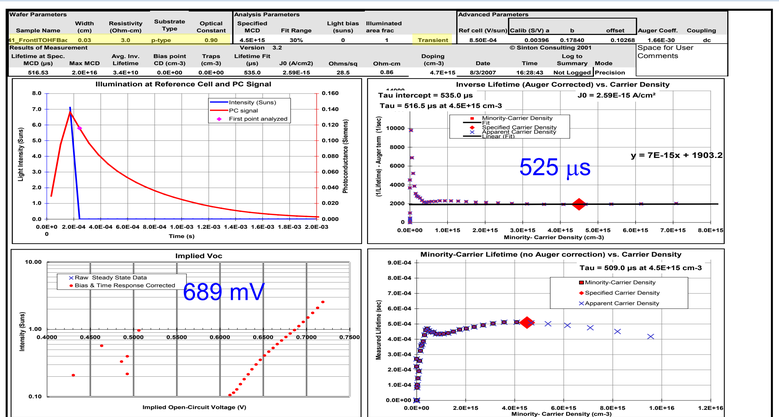



**Transparent Conducting Oxide Contact**
- Indium Tin Oxide (ITO) Thermal PVD
  90 nm : 180°C
  Front first then Back



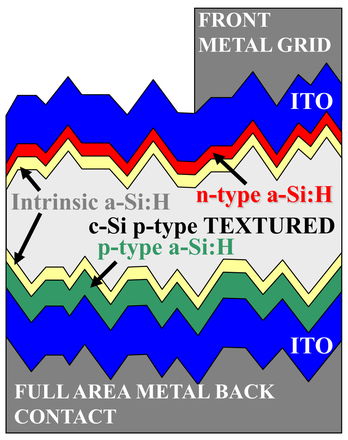

Typical reflectance curve for textured c-Si coated with ITO, no back metal

### Lifetime Measurement: ITO/a-Si:H/c-Si

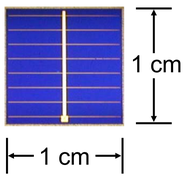



Lifetime data output from Sinton WCT-Boule lifetime tester and analysis after ITO deposition ITO/n/i/FZ-Si(p)/i/p for 19.1% device

## 3: Finished SHJ Solar Cell



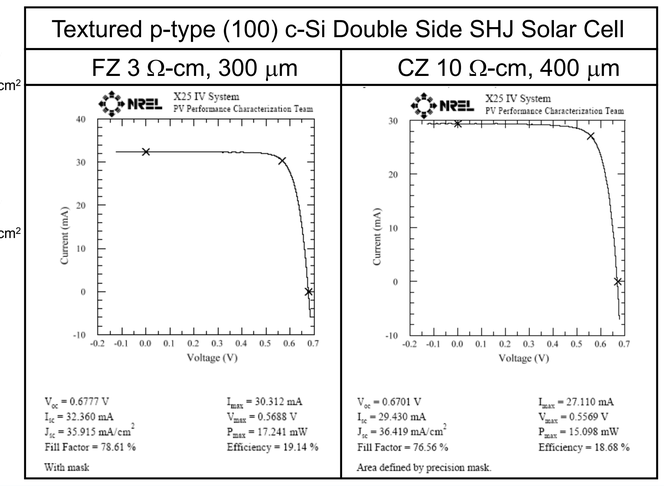

**Metal Contacts**
- e-Beam PVD : Ti/Pd/Ag/Pd
  50nm/60nm/4-5µm/60nm
  Back then Front
  **or**
- e-Beam PVD : Al on a-Si:H(p)
  Metal Back Contact
  1 µm : RT




## Confirmed Light I-V FZ and CZ

**Best p-FZ**
$V_{oc}$ = 678 mV
$J_{sc}$ = 35.9 mA/cm²
FF = 78.6%
η= 19.1%

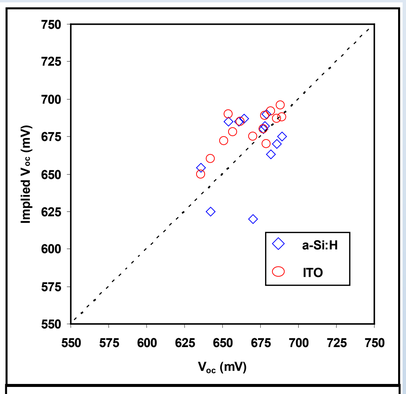
**Best p-CZ**
$V_{oc}$ = 670 mV
$J_{sc}$ = 36.4 mA/cm²
FF = 76.6%
η= 18.7%




## Lifetime Derived Implied $V_{oc}$: a-Si:H & ITO

**Potential Cell Performance vs. Actual Cell $V_{oc}$**

1. Lifetime is an average over whole measurement area
   - Infrared filter (RG-850)
2. Aperture mask for Light I-V
   - $V_{oc}$ of defined cell area
3. Figure shows good passivation of SHJ on c-Si
   - Grouping of cells between 650-690 mV

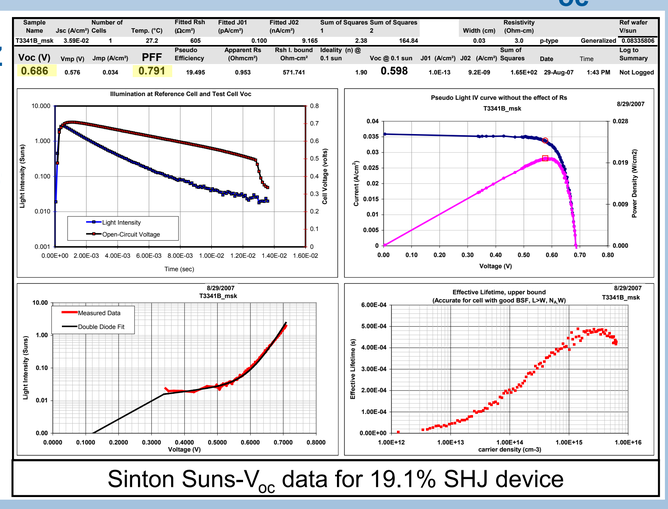



$V_{oc}$ from Light I-V measurements for finished solar cells vs. Implied $V_{oc}$ measured after a-Si:H(◇) and ITO (◯)

## Finished SHJ Solar Cell: Suns-$V_{oc}$

**Best p-FZ $V_{oc}$**
686 mV

**Pseudo FF**
79.1%



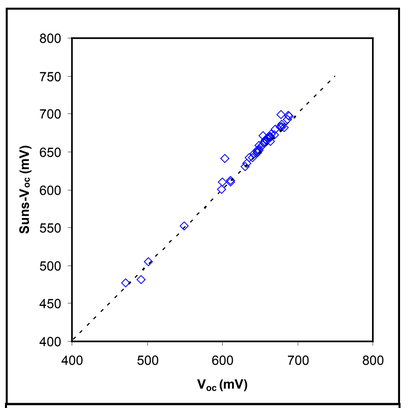

Sinton Suns-$V_{oc}$ data for 19.1% SHJ device

## Finished SHJ Solar Cell Comparisons

**Potential Cell Performance vs. Actual Solar Cell $V_{oc}$**

Sometimes Suns-$V_{oc}$ greater than Light I-V $V_{oc}$
- Flash vs. Simulator lamp
- Temperature control

Good agreement between AM1.5 LIV $V_{oc}$ and Suns-$V_{oc}$




$V_{oc}$ from Light I-V vs. Suns-$V_{oc}$ for finished solar cells

## Conclusions

**PCD Lifetime**
- Fast non-contact measurement
- Enabled by excellent surface passivation of a-Si:H on c-Si
- Implied $V_{oc}$ is a good parameter to infer final device performance

**Suns-$V_{oc}$ measurement**
- For SHJ devices Suns-$V_{oc}$ can be measure before metal contacts
- For finished devices combined with AM1.5 Light I-V can extract series resistance of metal contacts to solar cell

**These tools have sped up optimization of p-type SHJ processes yielding efficiencies of 19.1% for float-zone and 18.7% for Czochralski silicon.**

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